REPORT ON SESSION QG4 OF THE 13TH MARCEL GROSSMANN MEETING

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We summarize the talks presented at the QG4 session (loop quantum gravity: cosmology and black holes) of the 13th Marcel Grossmann Meeting held in Stockholm, Sweden.

Keywords: Loop quantum gravity; cosmology; black holes

The session was devoted to results on black holes and cosmology in the context of loop quantum gravity. It was a vibrant session where several new advances were highlighted. Among them, a much clearer picture emerges of the computation of the entropy in loop quantum gravity and several new insights into singularity resolution and how to treat time dependent quantizations arise in the context of cosmologies. Here is a summary of the talks presented:

Carlo Rovelli reviewed and provided context for certain important developments in the calculation of the entropy of horizons in loop quantum gravity. He started with the Unruh temperature (Ref. 1), the results of Kubo, Martin and Schwinger (Ref. 2) , discussed results of Tolman concerning gravitational thermodynamics and then proceeded to discuss the connection with the talks by Pranzetti, Perez and Bianchi in this session.

Alejandro Perez presented results obtained recently with Amit Ghosh and Ernesto Frodden and discussed in Ref. 3. Essentially they show that stationary black holes satisfy a very simple local form of the first law using a preferred family of local observers near the horizon and a suitable definition of energy for them. The same construction can be applied in the context of isolated horizons. When applied in the framework of loop quantum gravity, and treating the number of punctures in the horizon as a non-trivial observable, this leads to a grand canonical calculation that agrees with Hawking's semiclassical analysis for all values of the Immirzi parameter. It appears that matter inclusion is inevitable in the local calculation. And this could explain the flux of the entropy from its ultraviolet value (different from Hawking's calculation) to its infrared one (which coincides with Hawking's).

Eugenio Bianchi discussed several considerations concerning black hole entropy. Among them the use of the spin foam action to provide a classical theory with boundaries and the states that appear in the horizon dynamics in terms of spin foams (discussed in Ref. 4) and the quantum Rindler horizon, how to assign an energy to the quantum horizon that reproduces the Frodden–Ghosh–Perez result,

how to assign a temperature to the quantum horizon that leads to the usual result and how to use the Clausius relation to obtain the entropy, again leading to the usual result without fixing the Immirzi parameter.

Fernando Barbero discussed work in collaboration with Eduardo Villaseñor, presented in Ref. 5, concentrating on the subdominant corrections to black hole entropy. In particular it is observed that the corrections predicted by different models are different, their sign (which is relevant for black hole stability) is ensemble-dependent.

Jacobo Díaz-Polo summarized work with Aurelien Barrau, Thomas Cailleteau, Xiangyu Cao and Julien Grain presented in Ref. 6 concerning the imprint that is left in the Hawking radiation by the structure of the black hole area spectrum emerging in loop quantum gravity and how this could be used to differentiate it from other theories through the observation of black hole radiation.

Rodolfo Gambini discussed work with Néstor Álvarez, Saeed Rastgoo and Jorge Pullin concerning the quantization of spherically symmetric space-times coupled to a scalar field in loop quantum gravity. This requires a strategy to deal with the non-trivial algebra of constraints that emerges in this example. Strategies discussed included the use of uniform discretizations, discussed in Ref. 7 and a recently introduced family of gauge fixings that lead to a local true Hamiltonian presented in Ref. 8.

Daniele Pranzetti analyzed what happens when one matches the dynamical horizons framework with the local thermodynamical approach of Frodden, Ghosh and Perez. It allows to study the radiation process generated by the loop quantum gravity dynamics near the horizon, providing a quantum gravity description of the black hole evaporation. For large black holes it leads to a spectrum with a discrete structure that could be potentially observable. The results are discussed in Ref. 9

Ernesto Frodden discussed work with Alejandro Perez, Daniele Pranzetti and Christian Röken concerning the quantum origin of the entropy of rotating black holes. The approach is to consider a classical theory with an isolated horizon and identify the symplectic structure and in the quantization use a Chern–Simons topological theory with defects at the boundary.

Ivan Agulló presented a quantum gravity extension of the inflationary scenario obtained in collaboration with Abhay Ashtekar and William Nelson and discussed in Ref. 10. The key idea is to analyze quantum fluctuations over quantum spacetime whose homogeneous part is quantized using loop quantum cosmology. This approach overcomes two major difficulties of the conventional inflationary paradigm: the singularity and the trans-Planckian problems. It is found that for a large class of initial conditions cosmological perturbations yield results consistent with the WMAP data. Interestingly, there exists a narrow range of parameters for which distinct signatures from standard inflation are also possible. These results, thus provide an opportunity to test predictions of loop quantum gravity in future astronomical observations.

Edward Wilson-Ewing discussed about lattice loop quantum cosmology – an approach to go beyond the homogeneity assumption in loop quantum cosmology, presented in Ref. 11. In this approach, spacetime is divided in to homogeneous

and isotropic cells which are coupled with each other. The scalar constraint in this approach is composed of an ultralocal homogeneous term and an interaction term, which along with the diffeomorphism constraint, turns out to be preserved by the dynamics for small perturbations. Using the effective dynamics resulting from quantum constraints, loop quantum effects on linear perturbations can be studied.

Tomasz Pawlowski discussed a way the geometric degrees of freedom can be used for deparameterization in loop quantum cosmology. Pawlowski analyzed the case of a massive scalar field using volume and its momentum deparameterization, and reported the properties of quantum evolution operator and its eigenfunctions. The approach aims to overcome some difficulties which may arise in treating matter degrees of freedom as internal time. Preliminary results seem to suggest a non-trivial contribution to the energy density of the matter which may pose difficulties for renormalization for infinite modes.

Thomas Cailleteau discussed results on some observational consequences of loop quantum cosmology obtained in collaboration with Aurelien Barrau, A. Demion, Julien Grain, Jakub Mielczarek and Francesca Vidotto, and presented in Ref. 12. These results are based on the approach of considering an effective Hamiltonian which captures inhomogeneous degrees of freedom in loop quantum cosmology. The effective Hamiltonian incorporates the key effects which are expected to originate from the underlying quantum geometry. Effective constraints in this approach lead to anomalies, which require introduction of counter terms for their cancellation. With the inclusion of these counter terms, it is possible to obtain more consistent constraints on phenomenological parameters and a better understanding of some conceptual issues using the analysis of cosmological perturbations. The results are consistent with those of Edwin Wilson-Ewing.

Mikel Fernández-Méndez presented a hybrid quantization of an inhomogeneous inflationary model in loop quantum cosmology done in collaboration with Guillermo Mena-Marugán and Javier Olmedo and presented in Ref. 13. In the hybrid quantization approach, the key idea is to quantize homogeneous degrees of freedom using loop quantum gravity techniques, and treat inhomogeneities as Fock quantized perturbations over the homogeneous background. By fixing the gauge for local degrees of freedom at the classical level, properties of the quantum Hamiltonian constraint for the scalar perturbations were reported.

Daniel Martin de Blas discussed an approximation scheme developed in collaboration with Mercedes Martín-Benito and Guillermo Mena-Marugán to study inhomogeneities in loop quantum cosmology for the hybrid quantization of Gowdy T^3 model and Bianchi-I model which are locally rotationally symmetric. The quantization of both systems is performed including a massless scalar field. For the Gowdy model, the quantum Hamiltonian constraint can be written as a sum of the constraint for the homogeneous and isotropic spacetime and anisotropic and interaction terms arising due to inhomogeneity. The involved approximation, that concerns with considering eigenstates of the FRW operator, allows one to obtain approximated solutions. For the Bianchi I model, a solvable quantum Hamiltonian

constraint is obtained, being possible to construct semi-classical solutions and study their evolution.

Francesca Vidotto reviewed basics of spinfoams for cosmologists, and some of the key results which have been obtained so far in spinfoam cosmology and discussed in Ref. 14. The idea is to choose a suitable graph capturing inhomogeneous degrees of freedom and use coherent state techniques to compute transition amplitudes between two states of a universe. Under certain approximations, using this transition amplitude, an effective Hamiltonian capturing the quantum gravity corrections can be obtained.

Andrea Dapor gave two talks. First of these talks was on a joint work with Michal Artymowski and Tomasz Pawlowski on a non-minimally coupled inflationary model in loop quantum cosmology and presented in Ref. 15. The authors analyzed dynamics in the Planck regime and the effects of non-minimal coupling using an effective Hamiltonian. In the second talk, Andrea Dapor presented results on quantum field theory on Bianchi-I spacetime in loop quantum cosmology obtained in collaboration with Jerzy Lewandowski and Yaser Tavakoli and presented in Ref. 16. These results extend the previous work in loop quantum cosmology on quantum field theory in quantum Friedmann-Robertson-Walker spacetime to an anisotropic setting. By obtaining an effective spacetime geometry, Dapor and colleagues studied Lorentz invariance violation. They found that it may be possible for Lorentz violation to occur when the backreaction of quantum fields on quantum spacetime is included.

José Velhinho discussed uniqueness of Fock quantization of scalar fields with time dependent mass presented in Ref. 17. These results obtained in collaboration with Jerónimo Cortez, Daniel Martín-de Blas, Laura Gomar, Guillermo Mena Marugán, Mikel Fernández-Méndez and Javier Olmedo aim to shed insights on the ambiguities in the choice of Fock representation for the canonical commutation relations in quantum field theory in curved spacetime. Velhinho discussed that using unitary dynamics criteria and exploiting underlying spatial symmetries, a unique unitary equivalence class of Fock quantizations can be chosen.

Francesco Cianfrani discussed an approach to consider inhomogeneous cosmological spacetimes in loop quantum gravity developed in collaboration with Emanuele Alesci and presented in Ref. 18. In this approach the goal is to obtain a quantum cosmological model which can be obtained from loop quantum gravity with a proper reduction. To achieve this, an inhomogeneous Bianchi line element is considered and its quantization is proposed by a projection of the kinematical Hilbert space of loop quantum gravity to an appropriate subspace.

Acknowledgments

This work was supported in part by grant NSF-PHY-0968871, NSF-PHY-1068743, funds of the Hearne Institute for Theoretical Physics and CCT-LSU. This publication was made possible through the support of a grant from the John Templeton Foundation. The opinions expressed in this publication are those of the author(s)

and do not necessarily reflect the views of the John Templeton Foundation.

References

1. W. Unruh, Phys. Rev. D **14** (1976) 870.
2. R. Kubo, J. Phys. Soc. Jap. **12** (1957) 570; P. Martin, J. Schwinger, Phys. Rev. **115** (1959) 1342
3. E. Frodden, A. Ghosh, A. Perez, "A local first law for black hole thermodynamics", arXiv:1110.4055 [gr-qc] (2011).
4. E. Bianchi, "Entropy of Non-Extremal Black Holes from Loop Gravity," arXiv:1204.5122 [gr-qc].
5. J. F. Barbero G. and E. J. S. Villaseñor, Class. Quant. Grav. **28**, 215014 (2011) [arXiv:1106.3179 [gr-qc]]; Phys. Rev. D **83**, 104013 (2011) [arXiv:1101.3662 [gr-qc]].
6. A. Barrau, T. Cailleteau, X. Cao, J. Diaz-Polo and J. Grain, Phys. Rev. Lett. **107**, 251301 (2011) [arXiv:1109.4239 [gr-qc]].
7. R. Gambini, J. Pullin and S. Rastgoo, Gen. Rel. Grav. **43**, 3569 (2011) [arXiv:1105.0667 [gr-qc]].
8. N. Alvarez, R. Gambini and J. Pullin, Phys. Rev. Lett. **108**, 051301 (2012) [arXiv:1111.4962 [gr-qc]].
9. D. Pranzetti, Phys. Rev. Lett. **109**, 011301 (2012) [arXiv:1204.0702 [gr-qc]].
10. I. Agullo, A. Ashtekar and W. Nelson, Phys. Rev. Lett. **109**, 251301 (2012) [arXiv:1209.1609 [gr-qc]]
11. E. Wilson-Ewing, Class. Quant. Grav. **29**, 215013 (2012) [arXiv:1205.3370 [gr-qc]].
12. T. Cailleteau, A. Barrau, J. Grain and F. Vidotto, Phys. Rev. D **86**, 087301 (2012) [arXiv:1206.6736 [gr-qc]]; T. Cailleteau, J. Mielczarek, A. Barrau and J. Grain, Class. Quant. Grav. **29**, 095010 (2012) [arXiv:1111.3535 [gr-qc]]
13. M. Fernandez-Mendez, G. A. Mena Marugan and J. Olmedo, Phys. Rev. D **86**, 024003 (2012) [arXiv:1205.1917 [gr-qc]]
14. F. Vidotto, "Spinfoam Cosmology: quantum cosmology from the full theory," arXiv:1011.4705[gr-qc].
15. M. Artymowski, A. Dapor and T. Pawlowski, "Inflation from non-minimally coupled scalar field in loop quantum cosmology," arXiv:1207.4353 [gr-qc]
16. A. Dapor, J. Lewandowski and Y. Tavakoli, Phys. Rev. D **86**, 064013 (2012)
17. J. Cortez, G. A. Mena Marugan, J. Olmedo and J. M. Velhinho, Class. Quant. Grav. **28**, 172001 (2011) [arXiv:1106.5000 [gr-qc]].
18. E. Alesci and F. Cianfrani, "A new perspective on cosmology in Loop Quantum Gravity," arXiv:1210.4504 [gr-qc].